Baroclinic Data Assimilation in Korea/Tsushima Strait

Dmitri Nechaev
Department of Marine Science
University of Southern Mississippi
1020, Stennis Space Center, MS 39529
phone: (228) 688-2573 fax: (228) 688-1121 e-mail: dnechaev@ssc.usm.edu

Henry Perkins, Gregg Jacobs, Pavel Pistek, and William Teague
Naval Research Laboratory
Stennis Space Center, MS 39529

Alex Ostrovsky
Frontier Research System for Global Change, Tokyo, Japan

LONG-TERM GOALS

The long-term goal of the project is to develop, implement and verify an efficient 4D variational data assimilation algorithm into baroclinic primitive equation model. The algorithm is applied for the dynamically and observationally consistent reconstruction of the circulation in Korea/Tsushima Strait based on the synthesis of various types of observations in the region, including the data collected in the course of the "Dynamical Linkages of Asian Marginal Seas" (LINKS) program. The project enhances the scientific understanding of the circulation in the Korea/Tsushima Strait, a key component of water mass exchange between the Marginal Seas of Eastern Asia. We expect that the developed data assimilation approach will find wide application in the analysis of the dynamics of various straits and passages in the World Ocean.

OBJECTIVES

Dynamical modeling of seasonally varying baroclinic circulation in the Korea/Tsushima Strait based on assimilation of the LINKS data pursues the following scientific objectives:

- To quantify the seasonally varying circulation in the Korea/Tsushima Strait and to determine seasonal variability of the thermohaline structure in the Strait using the data assimilation algorithm.
- To estimate the leading dynamical factors determining the structure of the circulation and the major sources of the uncertainties of our estimate.
- To determine branching of the flow in the Korea/Tsushima Strait, it's seasonal variability and transports.
- To study the elementary dynamical process controlling the seasonal variability in the Tsushima Warm Current and their influence on the branching of the through-flow in Tsushima Strait.
- To provide the dynamically and observationally consistent boundary conditions for Japan/East Sea modeling.
- To formulate some recommendations on the design of the potential monitoring system in the Korea/Tsushima Strait.

Report Documentation Page

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302 Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**

4. TITLE AND SUBTITLE **Baroclinic Data Assimilation in Korea/Tsushima Strait**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Marine Science,,University of Southern Mississippi,1020,,Stennis Space Center,,MS, 39529**	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The long-term goal of the project is to develop, implement and verify an efficient 4D variational data assimilation algorithm into baroclinic primitive equation model. The algorithm is applied for the dynamically and observationally consistent reconstruction of the circulation in Korea/Tsushima Strait based on the synthesis of various types of observations in the region, including the data collected in the course of the ???Dynamical Linkages of Asian Marginal Seas??? (LINKS) program. The project enhances the scientific understanding of the circulation in the Korea/Tsushima Strait, a key component of water mass exchange between the Marginal Seas of Eastern Asia. We expect that the developed data assimilation approach will find wide application in the analysis of the dynamics of various straits and passages in the World Ocean.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

APPROACH

The core of the LINKS data set comprises the observations obtained from the array of current meters covering ten months period from May 1999 to March 2000 (Perkins et al., 2000, Jacobs et al., 2001a). Eleven bottom mounted ADCPs monitored the inflow and outflow from the Strait on two cross-sections providing an unparallel opportunity for quantitative analysis of the circulation in the Strait. Combined with available CTD measurements and historical data, this ten months long dataset ensures adequate observational constraints for a baroclinic model of Korea/Tsushima Strait. To recover from the data a fuller representation of circulation in the Strait, we developed a variational data assimilation system (DAS), which is able to treat different types of data in a statistically consistent way. Different correlation scales as well as temporal and spatial resolution of the assimilated data are taken into account by accurate definition of the data error covariances underlying the statistical settings of the assimilation algorithm.

The implementation of the baroclinic variational DAS for almost yearlong data set requires a lot of computer resources. The choice of the model for the data assimilation is conditioned by an attempt to find a trade-off between the complexity of a relevant dynamical model and the feasibility of the implementation of a robust assimilation scheme. For the reconstruction of the seasonal variability of the circulation in the Strait we use a non-eddy resolving primitive equation model with simple but adequate dynamics (Nechaev et al., 2001). Due to the implicit treatment of Coriolis acceleration, momentum diffusion, and pressure gradient terms, the time step of the model is limited by CFL condition for horizontal advection.

The closed boundary of the model domain is delineated along the 15m isobath. On the north, the region is bounded by the shelf break in the southern Japan/East Sea. The southern boundary of the region passes through the latitude of the Cheju Island. The region has three open boundary ports. For the reconstruction of the seasonal circulation in the Strait we keep moderate grid resolution (~7km) to ensure the low Rossby number non-eddy resolving dynamics of the model.

The model solution is controlled by the initial fields of T and S, open boundary distributions of T and S, open boundary velocities, and surface fluxes. The initial velocity field is diagnosed from the steady state model equations. To reduce the number of control variables, the control fields are expanded in a number of "structure functions" with characteristic time resolution of 2 weeks, and spatial resolution of approximately 30km.

WORK COMPLITED

The work reported here covers the second year of the development and validation of the DAS. During this period we conducted a number of data assimilation experiments aimed at the assessment of the DAS performance, estimating of the sensitivity of the optimal solution to the choice of the cost function weights, the cross-validation of the assimilation results with independent data (not included into the cost function), and producing of the final results of the reconstruction of the circulation in the Strait. The major experiments can be summarized as follows.

(1) Preparation of the first guess solution. Assimilation of historical data.
The optimization of the model solution in data assimilation experiments starts from the so-called first guess solution. As a first guess solution, we used the yearlong model run governed mainly by historical data: monthly mean climatologies prepared at RIAM on the base of JODC data and Russian surveys in

the region (Far-Eastern Regional Hydromet. Inst., Vladivostok). The open boundary conditions for this model run were computed as the solution of 3D variational assimilation problem (Nechaev et al., 2001). The optimal boundary conditions minimize the cost function, which (i) penalizes the deviations of the boundary conditions and the model solution from climatological data, (ii) attracts the transport to the LINKS transport estimates (Jacobs et al., 2001a), and (iii) enforces the smoothness of the model fields in the vicinity of the open boundary. This solution can be treated as an "ensemble mean" seasonal cycle of the circulation in the Strait. The results of these experiments allowed us to quantify how well the model is able to reproduce the seasonal cycle of climatological data, to assess the "model error" and to estimate the statistics of the misfits between the model solution and LINKS data.

(2) Assimilation of the ADCP data and historical data.
Starting from the obtained first guess solution, we performed a set of assimilations of the ADCP data using overlapping 3 months data assimilation intervals. The ADCP data has been low pass filtered with the cut off period of 2 weeks. The spatial correlation radius of velocity data was set to 30km. The first guess solution was used as background data to ensure the well-posedness of the data assimilation problem. One of the objectives of these experiments was to find out if the assimilation of the velocity data alone is able to reconstruct the details of hydrographic fields, which are missed in the climatological data. The comparison of the data assimilation results with contemporary CTD observations revealed 2% to 15% reduction of the misfit between the model solution and CTD data measured in the vicinity of the ADCP cites (Figure 1). This reduction depends strongly on the background stratification and varies from season to season.
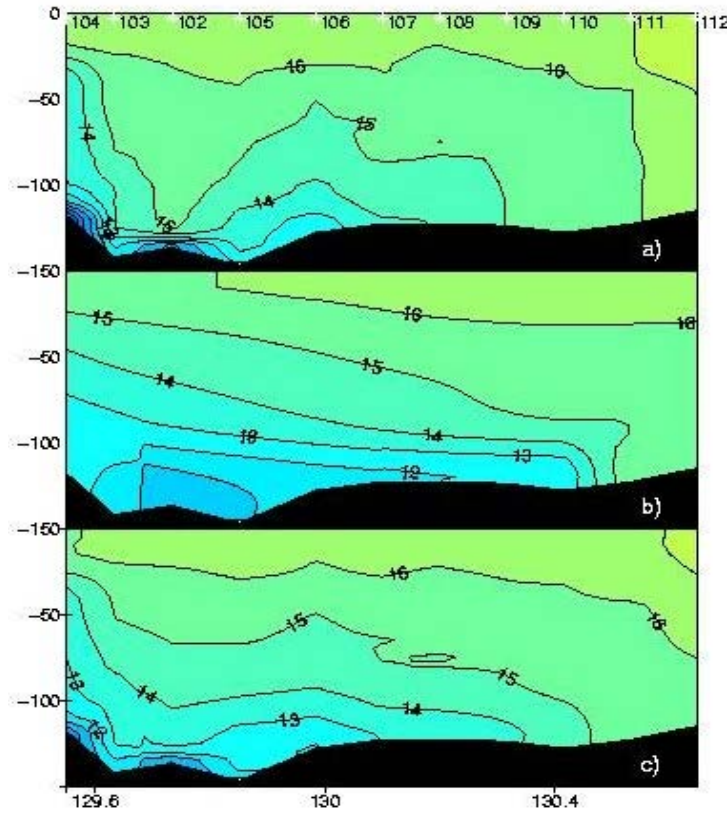
Figure 1. Temperature distribution on the CTD section (05/1999) along the "northern" line of ADCPs (Perkins et al., 2000) taken from CTD data (panel (a)), first guess solution (b), and optimal solution of ADCP data assimilation (c).

3

The continuous assimilation of ADCP data was also performed for the whole period of observation. It should be noticed that the data assimilation over 3 month intervals is approximately 10 times less expensive computationally and gives a better fit to the observations because of the smaller control space dimension and better convergence properties of the data assimilation algorithm.

(3) Assimilation of the ADCP and CTD data.
The ongoing research is focused on the data assimilation experiments, which combine historical data, LINKS ADCP data and CTD observations. The CTD data, which are currently available for data assimilation, include 3 CTD sections (05/1999, 10/1999 and 03/2000) performed on the same lines with ADCP observations, CTD survey in the northern part on the Strait (06/1999), and KODC CTD stations (1999-2000) covering the Korean part of the Strait. We conduct sensitivity and cross-validation experiments to assess the optimal correlation scales and variances of the CTD data. For the optimal choice of the cost function weights we will estimate the posterior error covariance of some important parameters of the optimal circulation in the Strait (such as monthly transports through the Tsushima Straight, monthly transports of the separate branches of the throughflow, monthly estimates of the heat transports through the Strait).

RESULTS

The experiments demonstrate that the data assimilation results describe realistically the large-scale transports of water masses through the Strait. The data assimilation algorithm is capable of reproducing the seasonal variability of the branching of Tsushima Warm current. The experiments showed high controllability of the circulation in the Strait by the open boundary conditions. The model is able to reproduce the major regimes of the through-flow splitting observed in the Strait (Perkins et al., 2000). The data assimilation provides more accurate and reliable estimates of the seasonal transport variability in the Strait compared to the estimates obtained by optimal interpolation of the velocity data (Jacobs et al., 2001). Data assimilation also allows to quantify the variability of heat and salt fluxes through the Strait - the estimate which requires dynamically and statistically consistent combination of various data.

On the other hand, because of the design of the DAS, the optimal solution does not reproduce a significant part of the data variability spectrum. The LINKS ADCP data revealed strong tidal signal (Book et al., 2001) and significant variability on inertial frequency (Jacobs et al., 2001b). It was also shown (Perkins et al., 2000), (Jacobs et al., 2001a) that the non-tidal velocity variations in the Strait contain very energetic short spatial scales (<50 km) as well as short temporal scales (<20 days), which are not described by the present DAS. The analysis of the throughflow transports (Jacobs et al., 2001a) shows that even for the velocity integrated over the Strait cross-sections there exist the fluctuations with temporal scale of a few days and more than 1Sv in magnitude. These fluctuations are superimposed on the seasonal transport variability characterized by the amplitude of approximately 1.7~Sv. The present version of the model is not designed to reproduce the details of mixing process in upper and bottom boundary layers and the influence of the boundary layer processes on the circulation. For example, the simplified parameterization of the sub-grid processes (prescribed turbulent diffusion coefficients, which vary in time and space) did not allow us to reproduce the exact rates of winter deepening of the mixed layer. As a result, in there exists a statistically significant (approximately three weeks) time lag between the model temperature and data at the 70m depth in late fall and spring.

The experience, which we gained during the work on the project, the experiments with the reconstruction of the seasonal variability of the circulation in the Strait, allowed us to realize the ways of the further development of the data assimilation method. The advance can be achieved through the development of the DAS in three directions:

- The explicit simulation of the processes unresolved in the model but present in the data.
- The inclusion of the more realistic turbulent closure into the model.
- More rigorous posterior error analysis and evaluation of the statistical assumptions.

We intend to apply the data assimilation method developed under this grant for the reconstruction of the baroclinic circulation in the Strait resolving processes of significantly smaller temporal and/or spatial scales, which are resolved by the data but not currently captured by the method. We also intend to implement the K-profile parameterization (KPP) to improve the representation of the vertical mixing processes in the model.

IMPACT/APPLICATIONS

The proposed research supports the Japan/East Sea DRI through provision of a complete coverage of low-frequency flow and water mass structure in the Strait. The proposed analysis will benefit ONR modeling for this region through provision of a key boundary condition for everyone working in the Japan/East Sea.

TRANSITIONS

The results of the 3D data assimilation have been transferred to Prof. Carol Anne Clayson and Dr. Maria Luneva (Purdue University, Department of Earth and Atmospheric Sciences). These fields will be used to pose the dynamically consistent boundary conditions in the Strait for the modeling of the Japan (East) Sea circulation under the ONR project "Studies of Deep Convection Processes Using Coupled Numerical Models: The Japan (East) and Labrador Seas".

The developed DAS and the procedure of variational adjustment of open boundary conditions has been transferred to Dr. Gleb Panteleev (Memorial University, St. John's, Newfoundland, Canada). Gleb Panteleev has applied the DAS for the study of baroclinic circulation on the Nova Scotia shelf.

RELATED PROJECTS

The project supports the ongoing field program in the area (especially the third phase of the LINKS Project) and the numerical modeling researches at NRL (Stennis Space Center). We benefit from the collaboration with the individuals working on "Yellow and East China Seas response to winds and Currents" and LINKS programs.

REFERENCES

Book, J. W., W. J. Teague, P. Pistek, H. Perkins, K. Thompson, B. H. Choi, G. A. Jacobs, M.-S. Suk, K. I. Chang, and J. C. Lee Tides in the Korea/Tsushima Strait: Observations and model predictions (submitted 03/2001).

Jacobs, G. A., H. Perkins, W. J. Teague, and P. J. Hogan. Summer transport through the Tsushima/Korea Strait. J. Geophys. Res., 106, (in press, 2001a).

Jacobs, G.A., J.W. Book, H. Perkins, and W.J. Teague, Inertial oscillations in the Korea Strait, J. Geophys. Res., (in press, 2001b).

Nechaev, D.A., Panteleev G.G. and Yaremchuk M.I., Baroclinic Model for 4D Variational Data Assimilation in Korea/Tsushima Strait, (Submitted to J. Geophys. Res., 2001).

Perkins, H., W. J. Teague, G. A. Jacobs, K. I. Chang, and M.-S. Suk, Currents In Korea/Tsushima Strait During Summer 1999. Geophys. Res. Lett., 27, 3033--3036, 2000.

Perkins, H., W. J. Teague, G. A. Jacobs, K. I. Chang, M.-S. Suk, J. C. Lee, J. W. Book, and C. O. Chan, 2001, Seasonal current variations around Tsushima Island (submitted 03/2001).